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Detection of Different Target Types in Realistic Terrain

by
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Hughes Aircraft Company
for the
Systems Development Department

MARCH 1979

NAVAL WEAPONS CENTER
CHINA LAKE, CALIFORNIA 93555

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Naval Weapons Center

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FOREWORD

This report documents a study conducted in 1978-79 by the Hughes Aircraft Company for the Naval Weapons Center, China Lake, California. The work was carried out under a target acquisition program supported by the Naval Air Systems Command under Airtask A03A3400/0C8B/7F55-525-000, and under the direction of Cdr. P. M. Curran, Naval Air Development Center, Warminster, Penn. Ronald A. Erickson was the technical monitor at NWC.

The Naval Weapons Center is conducting analysis and experimentation on several aspects of target acquisition, including detection and identification of targets by airborne sensors as well as direct vision. An algorithm has been developed which relates target acquisition performance to weapon delivery. This report describes a study to improve the data base required by the algorithm. The program to further expand this data base is continuing.

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30 March 1979

Under authority of
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(U) *Detection of Different Target Types in Realistic Terrain*, by G. E. Corrick, Hughes Aircraft Company. China Lake, Calif., Naval Weapons Center, March 1979. 36 pp. (NWC TP 6107, publication UNCLASSIFIED.)

(U) The effects of target and terrain characteristics on visual air-to-ground target acquisition were studied. Five target types, a portable bridge; a portable bridge with adjacent anti-aircraft artillery (AAA); a surface-to-air missile (SAM) site; a petroleum, oil, and lubricants (POL) supply dump; and a group of three tanks, were embedded into oblique aerial photos of real terrain at a simulated slant range of 1.6 km. Background scenes were selected to represent desert, desert/mountain, and rural terrain.

(U) The results of a search experiment showed that target type was the most important factor in determining acquisition performance, accounting for up to 40% of the experimental variance. The relative detectabilities of the target were found to group so that the bridge alone, the bridge with AAA site, and the SAM site were significantly easier to detect than the three tank group or POL site. These results are discussed in terms of the detectability of a target as related to the constraints on its possible scene location.

(U) Background was shown to be a significant effect, but accounted for about one-fourth as much of the variance as did target type. These results are compared to a previous similar study using multiple configurations of a single target type where background characteristics were shown to account for more variance. The implications of these results for target acquisition modeling are discussed.

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This work was supported by Contract Number N60530-78-C-0240 from the Naval Weapons Center, China Lake, California. R. A. Erickson monitored the contract and L. A. Scanlan was Program Manager. The author wishes to thank L. A. Scanlan, L. A. Olzak, and M. L. Hershberger for aid in initial planning and design of this study. D. W. Craig prepared the experimental imagery and D. C. Fulkerson and L. A. Olzak provided valuable assistance in statistical analysis. P. L. Barlow aided greatly by collecting the data.

INTRODUCTION

This interim report describes an experiment conducted to provide data to augment a target acquisition model which is part of a larger algorithm designed to compute the probability of an aircrew's successful delivery of air-to-ground weapons.[1] The present experiment focuses on the way in which target and terrain types influence visual target acquisition performance and it is an extension of a previous study demonstrating the importance of both target number and its interaction with terrain characteristics.[2] Specifically, the Olzak experiment dealt with detection of a single target type, a tank, presented in different numbers and configurations. The present experiment, on the other hand, is concerned with detection of wholly different target types, viz., an SA-6 surface-to-air-missile (SAM) site; a petroleum, oil, and lubricants (POL) supply dump; a group of three tanks; a portable bridge; and a bridge with surrounding anti-aircraft artillery (AAA). Target types such as these obviously differ both in the number of elements comprising a target and in configuration. The purpose of this experiment is to gather data on the relative detectabilities of these different target types in addition to investigating how the terrain type in which the target is located influences the relative detectability of these targets. These data, combined with those of the previous report by Olzak will be used in the formulation of a predictive model of target acquisition performance based on fuller appreciation of the interactive effects of target and terrain types. This modeling effort constitutes Phase II of the present contract and will be presented in a subsequent report.

TARGET ACQUISITION MODELING

The development of good, predictive mathematical models of the target acquisition process has obvious practical utility for military

[1] Naval Weapons Center. Launch Opportunity for Air-to-Ground Visually Guided Weapons. R. A. Erickson and C. J. Burge. China Lake, Calif., NWC, January 1978. (NWC TP 6005, publication UNCLASSIFIED.)

[2] Naval Weapons Center. Detection of Multiple-Vehicle Targets in Realistic Terrain. L. A. Olzak, Display Systems Department, Hughes Aircraft Company. China Lake, Calif., NWC, July 1978. (NWC TP 6061, publication UNCLASSIFIED.)

analysts and planners and as such has been actively pursued for more than 30 years. The resulting models are characterized by a number of different approaches and initial assumptions and vary widely in complexity. A detailed review of the models is not required here, having been excellently covered elsewhere.[3,4,5] A relevant point that emerges, however, is that both target type and terrain characteristics have been relatively ignored in target acquisition modeling. If included in a model, target effects are usually specified only by overall target dimensions and for the number of elements in the target. Target type, per se is usually not treated and hence a whole range of local area context effects are disregarded. Terrain classification, when explicitly dealt with in models, is typically treated by a global, unidimensional metric such as scene complexity, "busyness," or heterogeneity. Such measures, which assess scene characteristics in isolation from information about target type, are not good target acquisition performance predictors. A good example of this situation is given by the study of Zaitzeff[6], which used photos of real targets in real scenes. In this experiment a global subjectively measured heterogeneity measure was shown to be a reliable measure of scene complexity: that is, it was able to consistently discriminate scenes. However, this measure was shown to account for a small portion of the variance in the final regression equation and hence was not considered a good predictor of target acquisition performance.

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[3] C. P. Greening. "Mathematical modeling of air-to-ground target acquisition," Human Factors, Vol. 18 No. 2 (April 1976), pp. 111-147.

[4] Naval Weapons Center. Target Acquisition Model Evaluation: Final Summary Report, by C. P. Greening, Autonetics Division, Rockwell International. China Lake, Calif., NWC, June 1973. (NWC TP 5536, publication UNCLASSIFIED.)

[5] Naval Weapons Center. Target Acquisition Model Evaluation: Part 2. A Review of British Target Acquisition Models, by C. P. Greening, Autonetics Division, Rockwell International. China Lake, Calif., NWC, August 1974. (NWC TP 5536, Part 2, publication UNCLASSIFIED.)

[6] The Boeing Company. Target Background Scaling and its Impact on the Prediction of Aircrew Target Acquisition Performance, by L. P. Zaitzeff, Aerospace Group, Boeing Company, Seattle, Wash., December 1971. (AD737693 D180-14156-1, publication UNCLASSIFIED.)

Olzak explicitly tested the adequacy of the heterogeneity measure by testing detection performance by embedding targets in real scene photographs. In this study the targets consisted of a single tank, and groups and convoys of three or nine tanks. The scene heterogeneity measure was found to have high internal validity — scenes rated equivalent in heterogeneity produced equivalent performance. However, heterogeneity did not predict performance well: a correlation of only 0.18 was obtained between heterogeneity measures and detection performance.

Olzak[2] did find, however, that target characteristics provided good performance predictors. Performance varied directly with target number, i.e., one, three, or nine tanks, while target configuration was important only for the nine tank condition. The location within a scene of a target was also important, but only for the single tank condition where performance was better if the tank was located on or near a road. It was suggested that for increasing target numbers roads become less important cues to target location. These results highlight the importance of scene and target characteristics in predicting target acquisition performance. The purpose of the present experiment is to investigate such effects with different target types.

METHOD

Five target types were investigated in this study: 1) a group of three tanks; 2) an SA-6 SAM site; 3) a POL supply dump; 4) a bridge; and 5) a bridge with mobile AAA units adjacent. Each of these target types was embedded in six aerial oblique terrain background photographs, representing two each of three generic terrain types – rural, desert, and desert/mountain terrain. Subjects were assigned to one of five groups defined by target type; each subject thus saw all backgrounds but only one target type. The subjects were allowed 30 seconds to search the scenes for the pre-briefed target type, and dependent measures of time to detection and probability of correct detection were recorded.

EXPERIMENTAL DESIGN

This study manipulated two variables, target type and background, with repeated measures on the background factor, and independent measures on the target factor. The design is variously referred to as a mixed repeated-measure or split-plot design. Because the five groups of subjects each viewed a single target type, the subjects factor is nested within the targets factor. Thus, the between groups factor was target type, sampled at five levels and the within groups factor was background, sampled at six levels.

This design is somewhat different from the one employed by Olzak. In that study the within groups factor was a composite of three variables – scene complexity, complexity replications, and local context. The scene complexity measure was an adaptation of the heterogeneity measure developed by Ciavarelli, Wachter, and Lee[7] and consisted of paired-comparison ratings of scene complexity or busyness. Because this measure was found to correlate poorly with performance in the Olzak study, it was not included in the present experiment. This, of course, also obviated the need for a complexity replications factor. The final within groups factor from the Olzak study, local context, was a measure of whether a target appeared on or near roads as opposed to off roads. This factor is quite reasonable

[7] Naval Weapons Center. Terrain Classification Study, by A. Ciavarelli, L. Wachter, and W. Lee. Research and Engineering Division, Boeing Aerospace Company. China Lake, Calif., NWC, May 1975. (NWC TP 5766, publication UNCLASSIFIED.)

for describing the position of tanks as in Olzak's study, but lacks meaning when dealing with SAM sites or bridges as in this experiment. As such local context was deleted from this study as an experimental factor.

STIMULUS MATERIALS

Thirteen backgrounds were selected from the set supplied by the Naval Weapons Center and which were originally generated and described by Ciavarelli, et al[7]. Of the 12 backgrounds six were experimental scenes, five were training scenes, and two were used as targetless catch trials. In addition, five slides from a previous study[2], one each of the five target configurations, were used for preliminary training and to accustom the subjects to the operation of the apparatus.

Two major constraints were placed on selection of the experimental scenes. First, two each of rural, desert, and desert/mountain terrain types were desired. Second, the backgrounds were required to have reasonable locations in which to embed all of the five target types used in this study. The latter constraint meant that roads or rivers were needed for the bridge targets and a reasonably sized open space for the SAM site. These constraints were relaxed somewhat for the selection of the images for training purposes, as these images were considered of secondary importance to the experimental scenes.

One copy of each of the six experimental backgrounds was embedded with one of the five target types, for a total of 30 experimental scenes. Two copies of each background used for training were prepared and each was embedded with a single target type, again with the constraint of a reasonable target location. All backgrounds were embedded in a similar manner, described in the next section, and all scenes represented a 30° field-of-view (FOV) with targets at a slant range of approximately 1.6 kilometers. The slant range to the target had to vary slightly to provide reasonable target locations in each background.

TARGET EMBEDDING

An embedding procedure somewhat different from the photographic embedding of model targets described by Olzak was employed in this study. This technique consisted of an artist drawing the desired targets on clear overlays on enlargements of the background scenes, superimposing the overlay and background, and then photographically reducing the composite to the final proper size for presentation in 35-mm slide format.

After selection of the background scenes, the original 70-mm black and white negatives, supplied by the Naval Weapons Center and representing 60° fields of view taken from a height of approximately 300 meters, were processed into film positives enlarged four times and paper prints enlarged eight times. Tracing overlays were placed on the paper prints, and the various target types were sketched into the desired location at the proper scale. Individual overlays were made for each target-background combination to provide the best target fit into each background. Using the rough sketch overlays as a guide, an artist made refined ink drawings on clear acetate overlays affixed to the paper prints of the backgrounds. The artist was careful to simulate correct depression angle, target size, shadowing, and internal modulation of the targets using other elements of the scene as guides.

The finished artist's overlays were placed on a high contrast white background and photographically reduced by a factor of four and processed as negative transparencies. These negatives were then opaqued in the immediate target area and then contact printed into clear film positives. The result was a transparency containing only the target elements. These "target" film positives were then positioned over the previously generated four-time enlarged background film positives with the target elements in their proper location. The resulting composite was processed to produce a contact film negative.

The target-background negatives were marked to give the desired 30° FOV and photographed as final 35-mm film positives. These final positives were mounted in metal and glass slide mounts for use in Carousel slide projectors.

APPARATUS

The stimuli were presented via a two-channel projection system incorporating two Kodak Carousel 35-mm slide projectors, two Gerbrands shutters (# G1166), a half-silvered mirror combining glass, and a rear projection screen. Both projectors were focused within a 0.61 meter area of the projection screen.

The resolution of the projection system, measured on the rear-projection screen with a Buckbee-Mears resolution chart, was 3.8 optical lines/mm which is equivalent to 193 TV lines/inch. A control panel actuated the shutters and provided a digital timer whose onset was synchronous with the opening of the stimulus shutter. The subject was provided with a response key which stopped the timer, and a stylus to indicate the location of detected targets. A schematic diagram of the apparatus is shown in Figure 1.

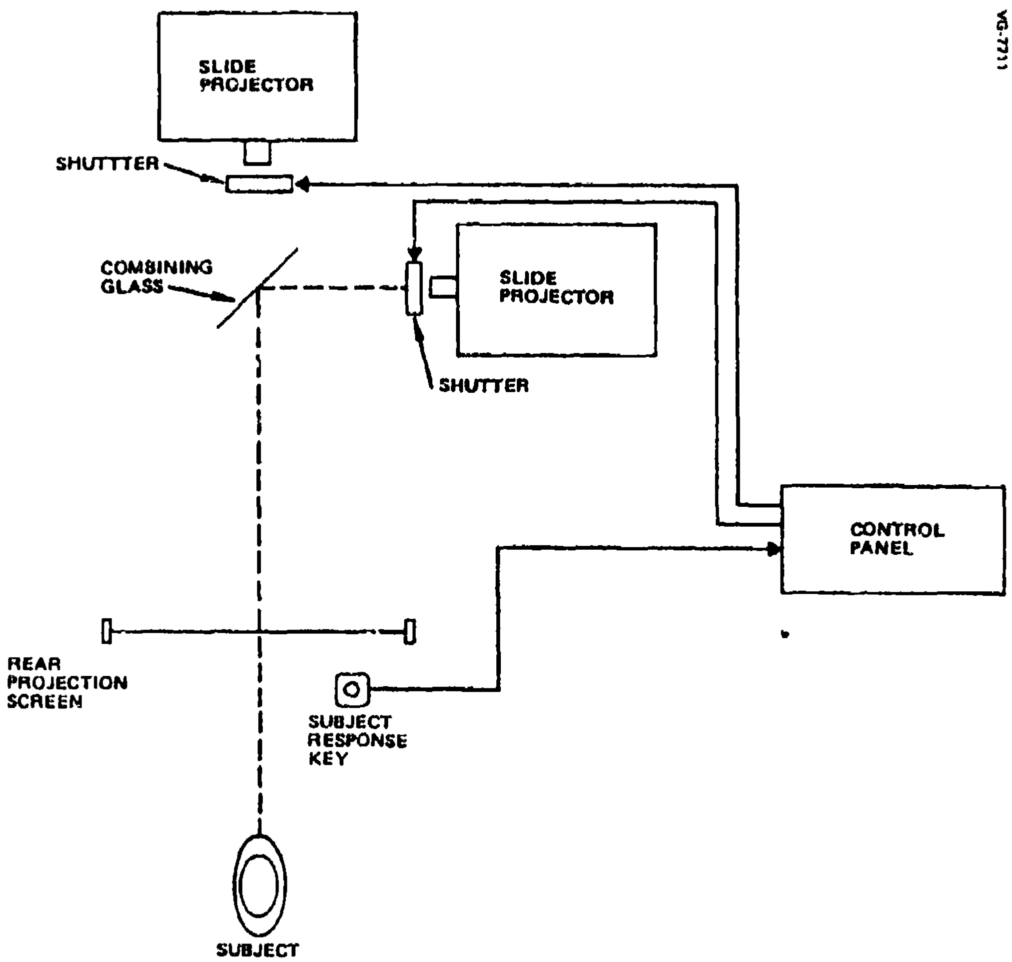

FIGURE 1. Schematic Diagram of Experimental Apparatus.

The screen was set 1.14 meters from the subject's eye; at this distance the 0.61 meter display subtended 30° FOV. A constant viewing distance was maintained by a chin and forehead rest.

SUBJECTS

The 25 subjects were Hughes Aircraft Company employees. All were screened to insure Snellen acuity of at least 20/20 with or without correction. Thirteen subjects had previously participated in other

target acquisition experiments; the other 12 subjects had never participated in a human factors experiment of any kind. Subjects were randomly assigned to one of the five target-type groups.

PROCEDURE

Subjects were run individually in 20-minute sessions which began with an assessment of visual acuity by a Snellen chart and followed by an explanation of the task and procedure. The room lights were dimmed and the subject shown a grid slide which adapted them to approximately the luminance of the experimental slides, 3.6 cd/m^2. The grid slide provided a fixation point to initiate trials and a set of coordinates to locate targets.

To familiarize the subjects with the task and apparatus, they were then shown five slides containing tank targets of various numbers and configurations taken from the Olzak study. The subjects were informed of the number of tanks and configuration before each of these slides and were permitted as much time as needed to locate the targets. The experimenter pointed out the location of missed targets.

Following this familiarization period, the subject was shown pictures of the five target types to be encountered on the next training slides. Again the experimenter informed the subject of the target type to be seen next, and feedback on the actual location of missed targets was provided. The last two training slides in this set contained the target the subject would search for in the experimental slides, and the subject was so informed.

After the presentation of the training slides, the six experimental and two catch slides were presented but without performance feedback. Upon completion of data collection, subjects were informed, if desired, of their overall performance.

The conduct of training and experimental trials was similar. Initially the subject fixated a cross at the center of the grid slide for 5 seconds. The experimenter said "ready" and following a 1-second delay operated the tachistoscope controls, simultaneously replacing the grid slide with a training or experimental slide and starting a timer. Subjects could search for up to 30 seconds. Locating a target, the subject pressed a button stopping the timer and pointed to the middle of the target configuration with a pointer. Simultaneously, the experimenter re-displayed the grid slide, and the subject read off the coordinates of the pointer's position. The experimenter then recorded the location and detection time, advanced to the next slide, and initiated the next trial.

RESULTS AND DISCUSSION

The two dependent measures taken in this experiment, detection time and probability of detection, were analyzed separately by analysis of variance and various post hoc comparisons designed to elucidate the nature of significant main effects and the locus of interactions. The dependent variables were analyzed in terms of the principal experimental factors: target effects, background effects, and the interaction of these factors.

In performing the data analysis of the detection times, a problem arises concerning how to treat incorrect trials or trials where no detection occurred. Such trials are tantamount to missing data when considering time to detection and as Winer[8] points out there is no satisfactory way to treat missing data unless the nature of the experimental response surface is adequately known. The solution employed in this experiment was to assign all incorrect responses the maximum allowable detection time of 30 seconds, and this was done chiefly to maintain consistency in data analysis between this study and the experiment of Olzak.[2] This procedure, however, is not without consequences. Chief among these is that the distribution of detection times becomes skewed and the variance of detection times is increased. Thus the standard deviation of all detection times is 12.2 seconds as opposed to a standard deviation of 5.7 seconds for only the detection times on correct trials. This brief discussion serves only to point out the problem and its consequences; however, in lieu of a more rational way of treating these cases, the analysis will incorporate the 30 second time score for missing data.

ANALYSIS OF VARIANCE

Tables 1 and 2 present the results for the overall analysis of variance of the time to detection and probability of detection data, respectively. The results are unambiguous. For both dependent variables, the main effects, target type and background, are highly significant, as is the interaction between these variables. The conclusion based on this analysis is that target type, background, and the interaction between target and background cause reliable differences in the time required for target detection and the probability of detection.

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8. B. J. Winer. Statistical Principles in Experimental Design. New York: McGraw Hill, 1962.

TABLE 1. Analysis of Variance Summary: Time to Detection.

Source	df	Error Term	SS	MS	F-Ratio	Probability Level	Eta^2	ω^2
Main Effects								
Target Type	4	S(T)	8715.63	2178.91	17.44	<0.001	0.3939	0.3692
Background	5	SB(T)	1730.19	346.04	6.33	<0.001	0.0782	0.0657
Interaction								
Target x Background	20	SB(T)	3719.57	185.98	3.40	<0.001	0.1681	0.1184
Error Terms								
S(T)	20		2498.77	124.94				
SB(T)	100		5464.86	54.65				
Total	149		22129.02					

TABLE 2. Analysis of Variance Summary: Probability of Detection.

Source	df	Error Term	SS	MS	F-Ratio	Probability Level	Eta^2	ω^2
Main Effects								
Target Type	4	S(T)	9.64	2.41	10.33	<0.001	0.2953	0.2649
Background	5	SB(T)	2.24	0.45	4.10	<0.01	0.0686	0.0517
Integration								
Target x Background	20	SB(T)	5.16	0.26	2.36	<0.01	0.1581	0.0903
Error Terms								
S(T)	20		4.67	0.23				
SB(T)	100		10.93	0.109				
Total	149		32.64					

While highly significant main effects and interactions imply a strong statistical relation between the independent and dependent variables, significance tests alone say nothing about the strength of the statistical relation. Simon[9] following the lead of Hays[10] advocates the use of a measure showing the strength of a significant effect. The traditional measure used by Hays is ω^2 which essentially is a correlation between the variance due to an experimental factor and the total experimental variance. Simon,[9] however, points out that ω^2 is a strength-of-effect measure for a population; for sample statistics Simon advocates Eta^2 which is the ratio between the sum-of-squares for the variable of interest and the total sum-of-squares. Tables 1 and 2 present both ω^2 and Eta^2 calculations. As can be seen, ω^2 is generally smaller than Eta^2. In this analysis both background and targets are treated as fixed effects, meaning they are the particular levels of these variables and are not samples from a larger population. Hence, the Eta^2 measure is more appropriate to describe the strength of effect.

More important, however, than the statistical particulars of the strength-of-effect measures are the results of the calculations. Both dependent variables present the same picture: the target type factor accounts for about five times the experimental variance as background type. This means that target type was a much stronger effect than background in determining target acquisition performance. Modeling efforts attempting to account for target and background effects thus take this result into consideration and the appropriate way to achieve this is to give a target type measure relatively more weight than measures of background characteristics.*

The Eta^2 calculations also show, for both dependent variables, that the interaction of target and background accounts for an appreciable amount of the total experimental variance. Given the predominance of the target main effect over the background main effect, the strength of the interaction is probably due mainly to target effects.

A significant interaction is usually interpreted as meaning that the effect on performance of one variable depends on the level of the other variable. The interaction in this equipment is taken to mean that target acquisition performance is determined chiefly by the target type

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*This conclusion will be tempered somewhat when a reanalysis of the data from Olzak's study is presented below.

9. Hughes Aircraft Co. Considerations for the Proper Design and Interpretation of Human Factor Engineering Experiments. C. W. Simon, Culver City, Calif. December 1971. HAC (Technical Report P73-325, publication Unclassified).

10. W. L. Hays. Statistics. New York: Holt, Rinehart, and Winston, 1963.

being considered, but this effect is modulated somewhat by the background in which the target appears. This interpretation is favored because it emphasizes the larger role of target type, than background, in determining acquisition performance.

The following sections will consider in more detail the nature and interpretation of the main effects and the locus of the interaction.

TARGET EFFECTS

Given the importance of target type, it is useful to consider the relative detectability of the five targets used in this study. Figure 2 plots the mean detection times for the various targets as well as the mean probability of error which is given by one minus the probability of correct detection.* Clearly the functions are very much alike and both show wide differences in the relative detectabilities of the targets.

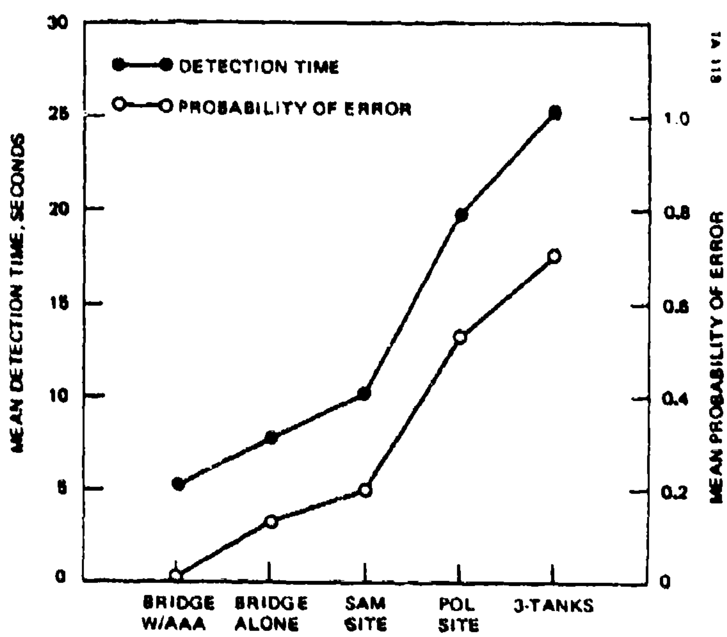


FIGURE 2. Mean Detection Time and Probability of Error for Different Target Types.

*The author recognizes that properly these data should be plotted as a histogram, since the abscissa plots a non-continuous variable. The data were plotted as shown for clarity.

In fact detection time and probability of correct detection are statistically correlated: the Pearson product-moment correlation between these variables is -0.967. As a result of this strong correlation, this and subsequent discussions will focus on the detection time variable, assuming that the same conclusions apply to the probability of detection.

These data were tested by a series of post hoc comparisons designed to determine where significant differences in mean detectability occurred. These differences were tested by a series of pairwise comparisons using the Newman-Keuls critical range method. The results of this test were identical for both dependent variables. The three tank group, while appearing to be the most difficult to detect, based on Figure 2, was not significantly different from the POL site. The POL site was more difficult ($p < 0.01$) than the SAM site, and the three tank group was also more difficult ($p < 0.01$) than the SAM site. The bridge alone did not significantly differ from the SAM site, but the POL and the three tank group were reliably more difficult than the bridge alone ($p < 0.01$ in both cases). The bridge with the adjacent AAA site did not differ from the bridge alone or SAM but was reliably different from the POL site and three tank group ($p < 0.01$ in both cases).

In summary, the comparisons show that these five targets fall into two reliably different groups in terms of mean detectability. The POL site and three tank group are not significantly different from each other and are the most difficult targets; the bridges are about equal to the SAM site and are reliably easier to detect than the tanks or POL site.

It would, of course, be appropriate at this point to provide a theory to account for the differences in the relative detectabilities of these targets. However, as that is a goal of Phase II of this effort it is premature to provide such a theoretical framework. One way to proceed is to first consider the experimental situation and the behavior of the subjects. In this situation the subject is searching for a prebriefed target that has been seen previously in the training trials. It is not unreasonable to conclude that from such information the observer has certain expectations as to where a target is likely to be located, much as a pilot would have expectations about where his prebriefed targets may be. Such expectations surely modify the observer's search behavior, by guiding the search behavior to terrain areas that may logically contain the target. Further, it is likely that targets which are highly constrained to logically appear in particular scene loci will be detected more rapidly, if only because fewer potential loci must be examined. Conversely, targets which, by their nature, may be located in a wide range of scene locations will require more search time.

In the context of this study, the above scheme provides a way of thinking about the relative detectabilities of the targets. Bridges are very constrained in their potential locations, always appearing on or near roads or rivers and consequently an observer's search strategy rejects inspection of areas without such features, lessening time to detection. SAM sites, which did not differ statistically in relative detectability from the two bridge targets, are also constrained, appearing chiefly in open, relatively flat terrain areas. Such areas are few in the presented scenes and are easy to locate quickly. The POL site and three tank group, however, logically may occur nearly anywhere in a scene and thus require more time to locate.

This admittedly speculative scheme is proffered only as a way of explaining, post hoc, the relative target detectability data discussed above. It appears to provide a framework within which both target type and background characteristics may be quantitatively formulated. Within this framework it may be possible to explain why some targets of equal visual subtense differ in detectability because of the scene context within which they must occur. Further, it may provide an account for differing detectability of targets on different backgrounds, because they have different potential areas within which different target types might appear, thus allowing an account of target-background interactions.

BACKGROUND EFFECTS

Figure 3 shows a plot of mean detection time and probability of error as a function of the six different backgrounds. It can be seen that the variability due to background is less than that due to target type, which is in accord with the results of the Eta^2 calculations discussed above. The statistical differences in these means were also tested by the Newman-Keuls method. In contrast to the similar data on target type discussed above, the pattern of results of this test was not in complete concordance for the two dependent variables; these differences, however, were minor. The time to detection data showed no significant differences among backgrounds 37, 71, 53, and 89. Background 37 was significantly ($p < 0.05$) different from background 6, but backgrounds 89, 53, and 71 did not differ reliably from 6. All backgrounds, save number 6, were reliably different from number 8.

The probability of detection data show that the only significant difference is that background 8 is significantly easier than backgrounds 37, 53, and 71 ($p < 0.05$) in all cases. All other comparisons are not statistically reliable.

It is impossible at this point to provide a theoretical account to explain these differences in detail. But a first step in this direction is provided by an informal classification of the scenes into desert

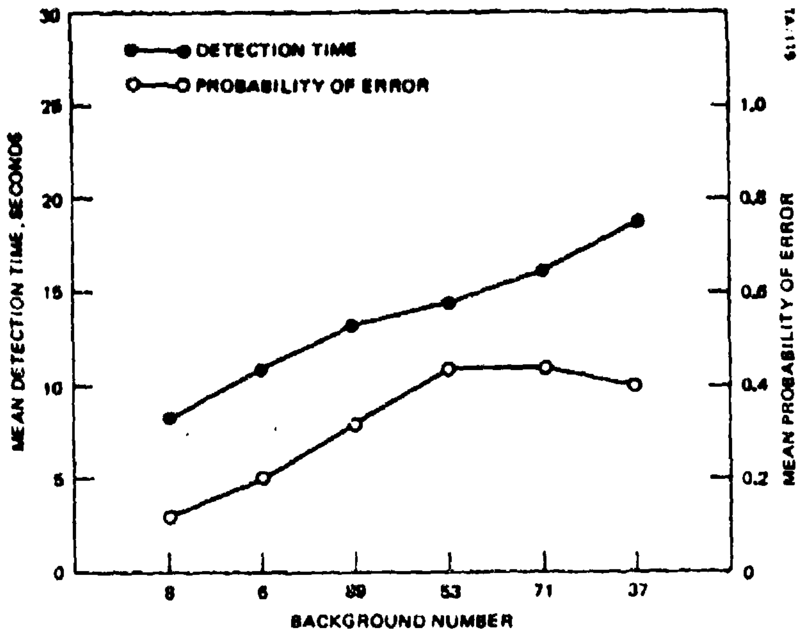
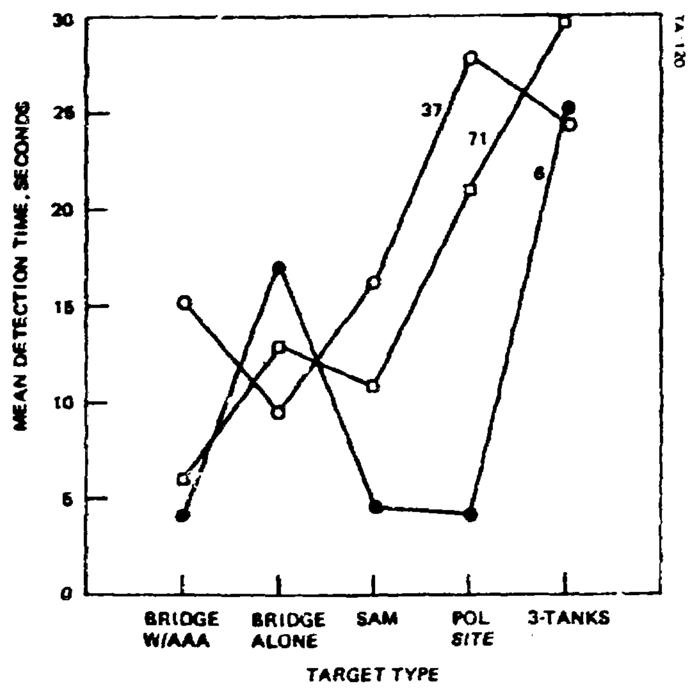


FIGURE 3. Mean Detection Time and Probability of Error for Different Backgrounds.

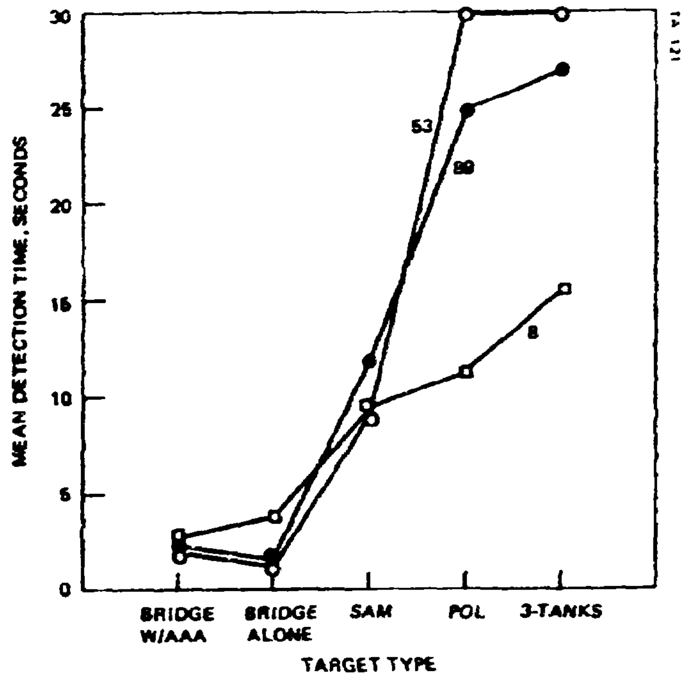
(no's. 6 and 89), desert/mountain (8 and 71) and rural (37 and 53) terrain types. Very generally, target detection is best in desert and desert/mountain terrain, and more difficult in rural terrain. However, these conclusions are tentative and based only on informal, global terrain-type classification. A more comprehensive account will be given in Phase II of this contractual effort.

INTERACTION

Figure 4 shows plots of mean detection time vs. target type with background as a parameter; these data are plotted on two axes for clarity. The presence of a significant interaction is shown by the fact that the ordering of the relative detectabilities of the targets, as shown in Figure 2, is not obtained for all backgrounds. Generally, this ordering is preserved for backgrounds 8, 53, and 89 (i.e., Figure 4b) but not for 6, 37, and 71 as in Figure 4a. That detectability of the target types varies as a function of background is, of course, simply another way of saying an interaction is present.



a. Mean Detection Time Plotted Against Target Type for Backgrounds 6, 37, 71



b. Mean Detection Time Plotted Against Target Type for Backgrounds 8, 53, 89

FIGURE 4. Example of Interaction.

The appropriate analysis to conduct to isolate the locus of the interaction effect is to test for the significance of simple main effects of one factor at the various levels of the other factor; this test essentially assesses the effect of variation in one factor at a time. In terms of this experiment, this test determines if there are significant differences between backgrounds at various levels of the target type factor. The results of this are presented in Table 3. A separate error term is shown for each factor because the appropriate error term is a "within-groups" mean square based on scores of the groups of subjects (i.e., the target-type scores, since the subjects factor is nested within target types) at each level of background. The results show a significant variation due to the background for all target types except the SAM site. Thus the detectability of the SAM site is the same over all the backgrounds employed in this study, while there are significant differences in performance for the other target types as a function of background. The last column of the table shows a calculation of an Eta^2 measure for this comparison. In this case Eta^2 was computed by

TABLE 3. Analysis of Simple Main Effect of Backgrounds at Different Target Types.

Source	df	SS	MS	F-Ratio	Probability Level	Eta^2
BKG at Bridge w/AAA	5	639.82	127.96	7.25	$P < 0.001$	0.1171
Error Term	20	352.81	17.64			
BKG at Bridge	5	1087.35	217.47	3.05	$P < 0.05$	0.1990
Error Term	20	1427.37	71.36			
BKG at SAM	5	369.37	73.87	0.939	NS	0.0675
Error Term	20	1573.07	78.65			
BKG at POL	5	2598.86	519.77	8.51	$P < 0.001$	0.4756
Error Term	20	1221.53	61.08			
BKG at 3-Tank	5	754.37	150.87	3.39	$P < 0.025$	0.1380
Error Term	20	889.97	44.50			

dividing the sum-of-squares for each term by the total sum-of-squares for the test as a whole. The results of this calculation show that most of the variance, almost 48%, is accounted for by the variation in performance over background for the POL target. This result appears reasonable in light of the variation in mean performance for the POL site, from a low of 4.14 sec to detection for background 6, a desert scene, to a maximum of 30 sec for background 53, rural terrain.

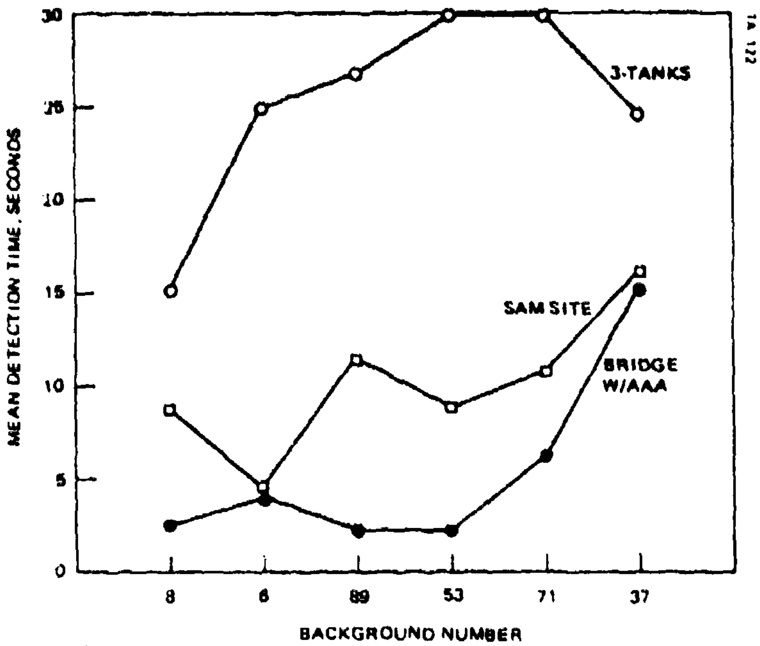
The complementary analysis, the simple main effect of target type at different background levels is clarified by re-plotting the data of Figure 4 as detection time against background with target as the parameter; these plots are shown in Figure 5, plotted on two axes for clarity. Again the fact that these plots do not show the same ordering of target detectability as a function of background as in Figure 3 simply demonstrates the presence of the interaction. The results of the test for the simple main effect of target at the different backgrounds is shown in Table 4. These data show significant differences in time to detection for the targets in all backgrounds except No. 8, a desert/mountain scene. The Eta^2 calculation, formed in the same way as discussed above, show that most of the variance in this test is due to background No. 53, a rural scene.

These data, taken together, show that target detection is influenced strongly both by the target type being searched for as well as the background. Adequate description of target and background effects would permit adequate predictions of such interactions.

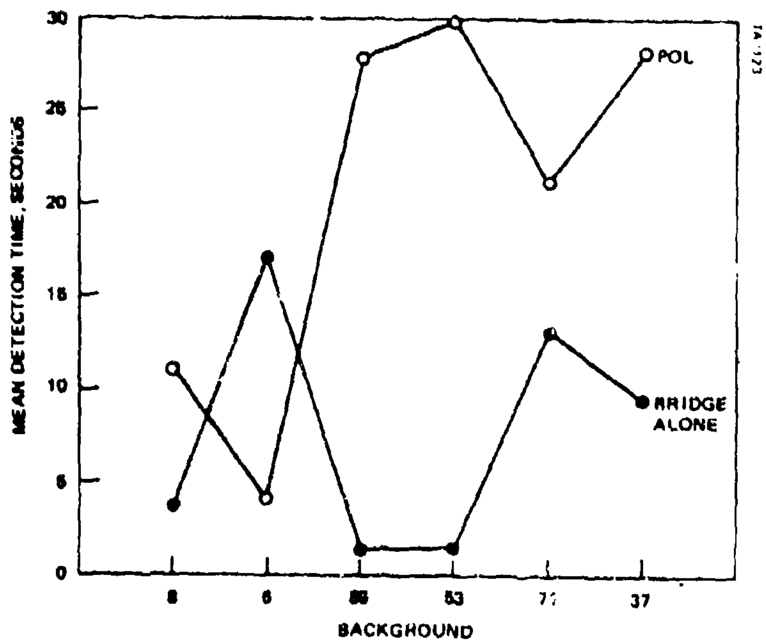
INFLUENCE OF GENERIC BACKGROUND TYPES

Another way to clarify the interaction effects is to collapse backgrounds into three 'generic' types; that is scenes 6 and 89 represent desert terrain, scenes 8 and 71 represent desert/mountain terrain, and rural terrain is represented by scenes 37 and 53. It must be remembered that these are informal classifications only for the purpose of clarifying the data, but examination of the actual scenes in Appendix A shows that these classifications are reasonable.

Figure 6 shows detection performance for the five target types as a function of the generic scene classification. Tests of the simple main effect of target with backgrounds collapsed into these generic types were significant beyond the $P < 0.01$ level at all three generic types, which again shows the importance of target type. However, Figure 6 shows the large influence of the rural scene on detectability of the POL site. Since in these scenes the POL site was located along or near tree lines, it is not surprising this target in these backgrounds was more difficult.



a. Mean Detection Time Plotted Against Background Number for Three Tank, SAM Site, and Bridge with AAA Targets



b. Mean Detection Time Plotted Against Background Number for Bridge Alone and POL Site Targets

FIGURE 5. Example of Interaction.

TABLE 4. Analysis of Simple Main Effect of Target Type at Different Backgrounds.

Source	df	SS	MS	F-Ratio	Probability Level	Eta^2
TGT at No. 8	4	549.08	137.27	2.07	N.S.	0.0689
Error Term	20	1327.83	66.39			
TGT at No. 6	4	1868.20	467.05	8.99	$P < 0.001$	0.2346
Error Term	20	1039.63	51.98			
TGT at No. 89	4	2909.92	727.48	13.62	$P < 0.001$	0.3650
Error Term	20	1068.15	53.41			
TGT at No. 53	4	4192.88	1048.22	37.33	$P < 0.001$	0.5265
Error Term	20	561.62	28.08			
TGT at No. 71	4	1786.62	446.62	4.26	$P < 0.025$	0.2243
Error Term	20	2098.82	104.94			
TGT at No. 37	4	1129.18	282.29	3.02	$P < 0.05$	0.1418
Error Term	20	1867.45	93.37			

The effect of background on target type is shown in Figure 7. Here simple tests of the main effect of background at various levels of target type revealed significant differences only for the bridge with AAA site and POL target ($p < 0.03$, $p < 0.01$, respectively). Thus, the other targets were not significantly more or less detectable in any generic background type.

GENERALITY OF RESULTS

The results presented to this point have treated both backgrounds and target types as fixed effects; that is, the analysis has assumed that the levels of these two factors used in the experiments are the only ones of interest. Thus, the inferences drawn from data analyzed in this way are confined only to the levels of the factors actually examined, obviously limiting the generality of the results. Testing targets or backgrounds on random effects, however, is based on the

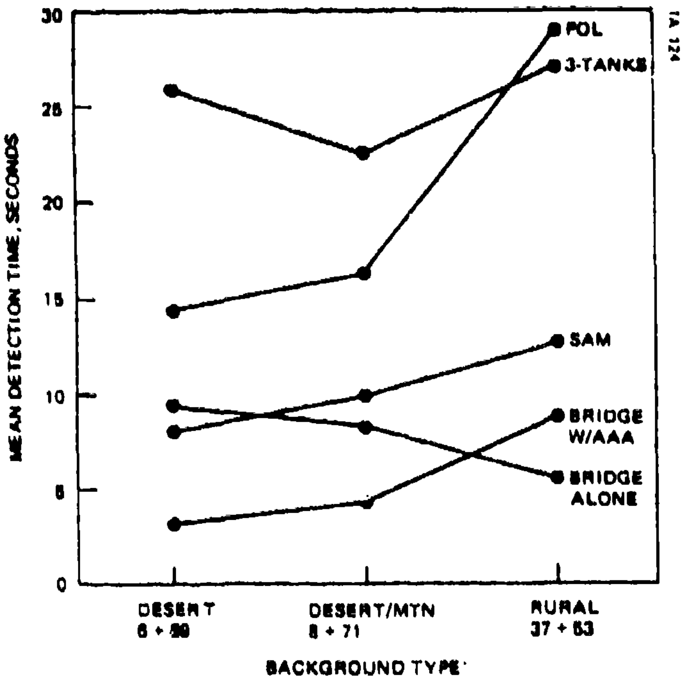


FIGURE 6. Mean Detection Time as a Function of Generic Background Type for Different Target Types.

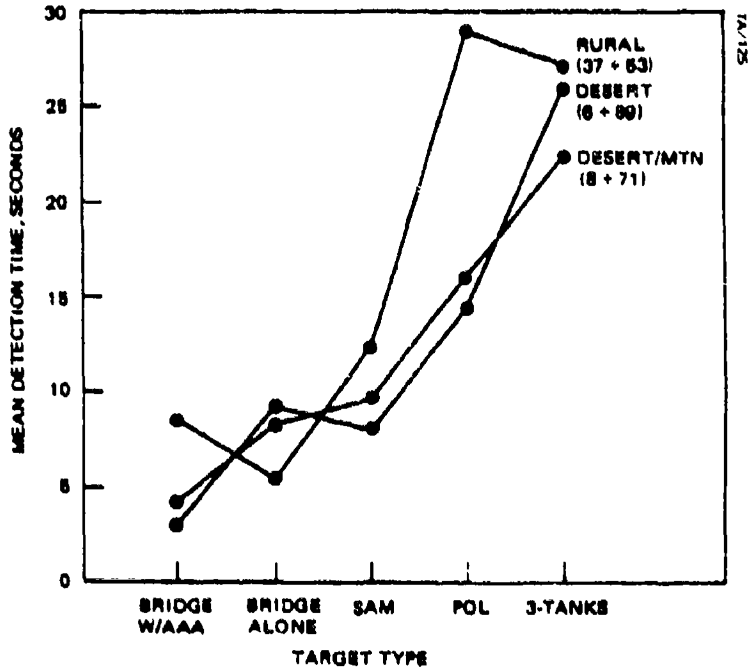


FIGURE 7. Mean Detection Time as a Function of Target Type for Generic Background Types.

assumption that the levels of these factors are simply representative of a larger population of possible factor levels. Analyzing the data in this way permits answers to questions such as whether there are significant differences in target detection over all backgrounds or if background influences target detection for all types of targets and not just those represented in this study.

The results of this analysis are straightforward. When the target factor is analyzed as a random effect, which is equivalent to asking the question whether there is a significant background effect assuming these targets are sampled from a larger population, a non-significant F-test is obtained ($F_{5,20} = 1.86$, $p = 0.15$). This result implies that the significant background effect obtained when targets are a fixed effect does not generalize to all possible targets. Thus, the significant effect due to background in this experiment is specific to the targets used here.

The results of the analysis with background as a random effect were different. A significant target effect ($F_{4,20} = 11.72$, $p < 0.001$) in this case implies that significant differences in target detectability will obtain for any background type that is examined. This conclusion supports the idea presented above that target effects account for more variance and, therefore, are relatively more important than background type in determining target acquisition performance.

CUMULATIVE PROBABILITIES OF DETECTION

A means for examining the joint results of time to detection and probability of detection is to plot the cumulative probability of detection as a function of time. Figure 8 shows cumulative probabilities for the various target types. The terminal probabilities show that the bridge with the AAA site is the most likely to be detected followed by the bridge alone, SAM site, POL and finally the three tank group. It can be seen that the initial slopes of the two bridge targets and the SAM site are very similar, with about 60% or more of correct detections occurring within the initial five seconds. Interestingly, the SAM site data appears to be shifted to the right by about two seconds in comparison to the bridge targets; no SAM detections occur within the first two seconds, while there is a 0.34 probability of detecting a bridge and a 0.26 probability of detecting the bridge with the AAA site in the first two seconds of search. This more rapid detection probably reflects the advantage provided by locating a target on or near a road, as clearly demonstrated in the study by Olzak[2]. Roads seem to be powerful cues to the search process and are most likely the first terrain features to be searched.

Detection of the POL and three tank target is much slower and less likely to be successful. The terminal probability of detection for the three tank group is only 30%, which is much lower than any other target. Initially, it was thought that the subjects in this group may have performed poorly due simply to random sampling. Another group of

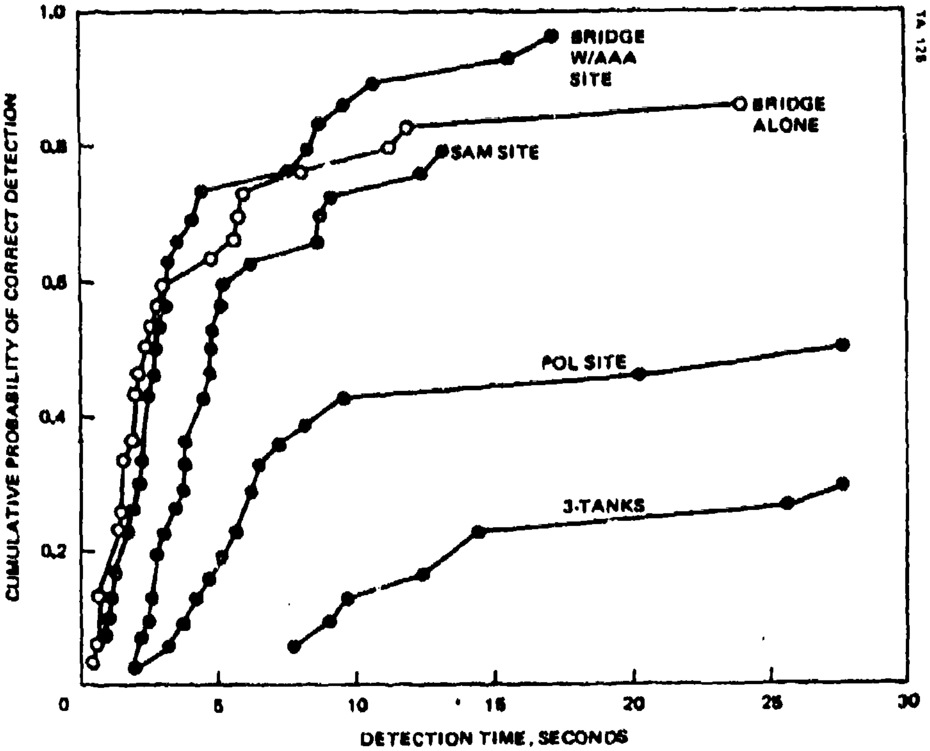


FIGURE 8. Cumulative Probability of Correct Detection as a Function of Time for Different Target Types.

five subjects was run to determine if this was the case, but their data were virtually identical to the original group and therefore it was concluded that the original three tank group data were accurate and the new data were not used for further analysis.

The cumulative probabilities of detection for the three tank group and POL site seem to show that for these difficult targets the full 30 seconds search time was not utilized. The POL and tank group reach asymptotic levels of detection probability after about 10 and 15 seconds respectively; the remainder of the search time does not seem to improve performance. This suggests that the initial few seconds of search are the most critical, and if the observer has not detected the target within this time there is little likelihood of doing so given more time. This result has implications for modeling target acquisition performance in that the performance during the first few seconds of search ought to be a good predictor of terminal performance and that modeling ought to concentrate on this time period.

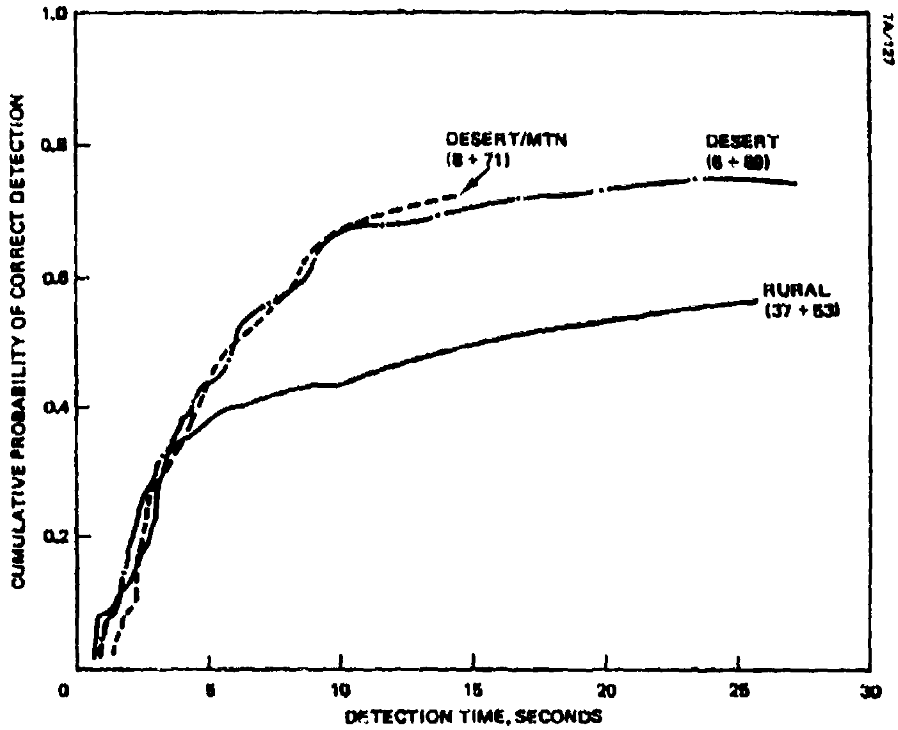


FIGURE 9. Cumulative Probability of Correct Detection as a Function of Time for Generic Background Types.

The cumulative probabilities of detection for the generic backgrounds, rural, desert, and desert/mountain, are presented in Figure 9.* Here it can be seen that the plots are roughly similar for the desert and desert/mountain types, but the rural scenes have lower initial slopes and lower final probability values. It is interesting to note that in the plot for the rural scenes the contributions of the two scenes (37 and 53) is somewhat different in that the maximum detection time for any target in scene 53 was about 5 seconds. All data in the composite plot beyond 5 seconds was contributed only by scene 37. It is not clear at this point why one rural scene permitted much more rapid detection; this will be investigated more fully in the modeling phase.

*The data points in this figure were omitted for clarity. The curves are tracings of the data points.

COMPARISON TO OLZAK'S STUDY

The design and procedures of the Olzak[2] study were essentially the same as those of the present study. This permits an assessment of the relative strength of target and background effects when a single target type is presented in different numbers and configurations, i.e., Olzak's study, in comparison to the present study, which used fundamentally different target types. In the Olzak study there were three within group variables: scene complexity, complexity replications, and local context. For the purposes of comparison to the present study, these variables were collapsed to form a single within group variable of background type. An ANOVA was performed on Olzak's data, and the results are shown in Tables 5 and 6 for time and probability of detection data, respectively.

The re-analysis of Olzak's data shows that both main effects and the interaction are highly significant for both dependent measures. This, of course, is exactly the same overall result as in the present experiment. A difference occurs when the Eta^2 calculations are examined. The present study showed that the target effect accounts for up to five times as much variance as the background effect. Olzak's data, on the other hand, show that background effect contributes slightly more (for the time data) or just slightly less (for probability data) variance than the target effect. This difference is not attributable to the overall variance accounted for in the experiment, which is comparable for both dependent variables between the two studies. That is, time and probability accounted for 64% and 52%, respectively, in this experiment versus 60% and 49% in Olzak's study. In any case, the difference lies in the apportionment between the main effects and interaction of the total variance accounted for in the experiment.

This difference reflects the contrasting emphasis between the two studies. It seems reasonable to conclude that a single target type, in this case a tank, differing only in number and configuration, would account for less overall experimental variance than target types differing fundamentally in kind, as well as number and configuration. This is precisely the result shown by comparisons of the Eta^2 values between both experiments.

That background accounted for more variance in Olzak's study may also be due to the fact that 12 backgrounds were used in that study as opposed to only six in this one. But the fact that background accounts for just about twice as much variance in Olzak's study as the present one is probably coincidental.

A final reason for the smaller contribution of background to the overall experimental variance in the present study lies in selection of backgrounds. Five of the six backgrounds in this study were used in Olzak's, and these five were contrasted to the other seven in that

TABLE 5. Analysis of Variance Summary: Time to Detection - Reanalysis of Data from Olzak, 1978.

Source	df	Error Term	SS	MS	F-Ratio	Probability Level	Eta^2	ω^2
Main Effects								
Target Type	4	S(T)	6076.65	1519.16	11.29	<0.001	0.1487	0.1351
Background	11	SB(T)	7906.84	718.80	11.61	<0.001	0.1935	0.1765
Interaction								
Target x Background	44	SB(T)	10565.11	240.12	3.88	<0.001	0.2585	0.1915
Error Terms								
S(T)	20		2691.12	134.56				
SB(T)	220		13625.80	61.94				
Total	299		40865.52					

TABLE 6. Analysis of Variance Summary: Probability of Detection - Reanalysis of Data from Olzak, 1978.

Source	df	Error Term	SS	MS	F-Ratio	Probability Level	Eta^2	ω^2
Main Effects								
Target Type	4	S(T)	6.42	1.61	7.76	<0.001	0.1112	0.0963
Background	11	SB(T)	6.04	0.50	4.74	<0.001	0.1047	0.0816
Interaction								
Target x Background	44	SB(T)	15.66	0.36	3.08	<0.001	0.2714	0.1795
Error Terms								
S(T)	20		4.13	0.21				
SB(T)	220		25.46	0.12				
Total	299		57.71					

study. The mean time to detection, collapsed over all target configurations, for the five used in this study was 13.7 sec versus 10.74 sec for the other seven. This difference was tested as a contrast on marginal means by an F-test and the obtained ratio was $F_{1,20} = 4.74$ ($P < 0.05$). Therefore, the backgrounds used in this experiment were significantly more difficult than the other backgrounds from Olzak's study. It is likely that these five are more homogenous in terms of the variance they contribute, and therefore it is not unusual that the overall variance contributed by background is less in the present study.

It seems, however, that the difference in the proportion of variance accounted for by target and background between the two studies does reflect an important consideration for target acquisition modeling, namely that background type is more important in determining performance when a single target type is under consideration, than when multiple target types are being considered. The relative effects of background must be weighted to a greater or lesser degree, depending on what purposes a model is being exercised.

An operational situation of interest illustrating this point might be one in which a target acquisition model is being used to compute the weapon resources to be used against tactical targets. If, based on other intelligence, the mission planner knows that the strike is to be only against tank formations, then the background component of the model ought to be given greater weighting than if a mission is being planned against a variety of tactical targets. It remains an empirical question, however, to determine if target acquisition modeling is significantly improved by a differential weighting of background effects, and if so, whether the improvement is justified by the increased cost and additional complexity of such a weighting scheme.

A final point of comparison between the two studies regards the relative performance of the three tank groups in the two studies. The cumulative probabilities for the three tank group in this study are very much different than those of the Olzak study, with the final probability of detection levels being 30% in this study as opposed to about 70% in the previous study. This difference probably reflects differences in the target placement within the scenes, as a conscious effort was made in the present study to place the three tank group in different locations within a scene than in the Olzak study. However, until better metrics are developed relating the way targets interact with backgrounds, further speculations on this difference is best suspended.

CONCLUSIONS

The data obtained in this experiment serve to reinforce the notion that target and scene characteristics and their interaction are critical in determining target acquisition performance. As such, these characteristics require a more quantitative formulation which expresses the importance of the interactive effects of target type and background characteristics. However, as these data are intended to be incorporated into a data base which will permit the later development of such a quantitative formulation, it is not the purpose of this interim report to provide a theory to account for the observed effects. The following paragraphs will briefly summarize the qualitative aspects and implications of the data obtained in this summary.

TARGET EFFECTS

By far the most important factor in determining the level of target acquisition performance is target type. Statistical analyses showed that the five target types used in this study fell into two reliably different groups in terms of relative detectability. The bridge target, the bridge with an adjacent AAA site, and the SAM site were reliably easier to locate than the POL supply dump or three tank group. The mean time to detection and probability of detection for these groups were, respectively, 7.74 seconds and 0.88 probability versus 22.58 seconds and 0.39 probability. One way to account for these results is to consider that the detection time for a specific target is inversely related to the degree of constraints on potential location of the target. That is, targets which are highly constrained to appear in certain scene contexts will have shorter detection times. This effect is perhaps due to the observer's expectation of potential target locations modifying search behavior. It would be highly desirable to test this notion directly by monitoring eye movements during search with these or similar target types.

BACKGROUND EFFECTS

Background type unexpectedly accounted for a small proportion of the variance in this experiment in comparison to another related study[2]. However, this result is obtained because widely different target types were being compared here as opposed to a single target type differing in number and configuration. This result also implies that prior knowledge of target type subtly modifies the influence of scene characteristics on search behavior, but the nature of this modification is unclear and cannot directly be addressed in experiments of this kind.

IMPLICATIONS FOR MODELING

These results have some important implications for the formulation of predictive models of target acquisition. First, target type will have to be quantified in some way other than a simple size or number specification. For example, if the number of elements comprising the target was the only quantification of target type, the SAM site, which contained 8-10 elements, should have been the easiest target to find, while the bridge alone should have been most difficult, results which, however, did not obtain. A quantification of target type ought to include the notion that different targets differ fundamentally in the scene contexts within which they might be found.

Background effects, while important, seem to be outweighed by target effects when widely differing targets are being compared. This implies that the weighting given to background effects in a model cannot be constant but must vary according to what comparisons are desired.

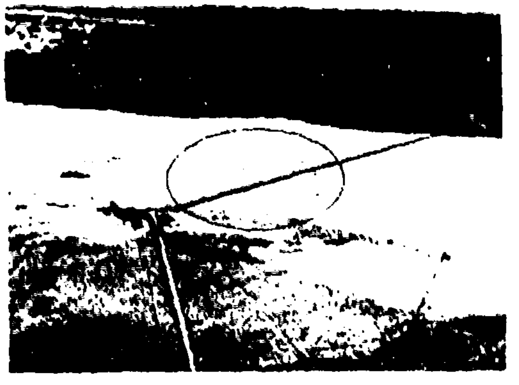
Further, since background and target type interact strongly, a useful quantification of terrain might be one which considers the number of potential locations for a particular target, rather than a global measure of the overall characteristics of a scene.

Target acquisition is a very complex behavior, and any single experiment cannot fully account for all the variations in performance. The present results do suggest some intriguing effects and some potentially useful ways to think about this complex behavior.

IMPLICATIONS FOR OPERATIONS

An important use of target acquisition models is determining the allocation of minimum weapon resources to be used in a tactical strike to achieve a given probability of success. The present results, at this stage of development, do not permit quantitative answers to such questions. However, in a qualitative way these data show that because the probability of error and the time to detection are less for the bridge targets and the SAM site, in comparison to the POL and three-tank target, fewer resources might be allocated for a stike against the former targets. The results also show that targets located in rural terrain would require more resources than those located in desert or desert/mountain terrain. These conclusions assume that resource allocation is determined by the time or probability of detection. This, of course, is an oversimplification. Further speculations on how these data may ultimately be used, however, are well beyond the scope of this report.

Appendix A
EXAMPLES OF EMBEDDED TARGET TYPES



Background #6: SAM Site

Background #8: Bridge

Background #37: POL Site

Background #53: Bridge with AAA Site

Background #71: Three Tanks

Background #89: POL Site

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